Green Run Modal Test of the NASA Space Launch System Core Stage

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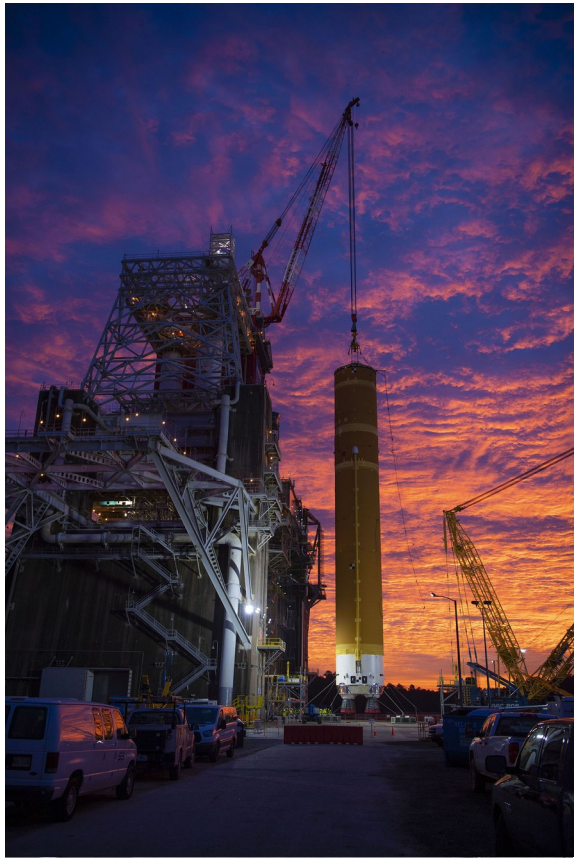
MARSHALL SPACE FLIGHT CENTER

National Aeronautics and Space Administration

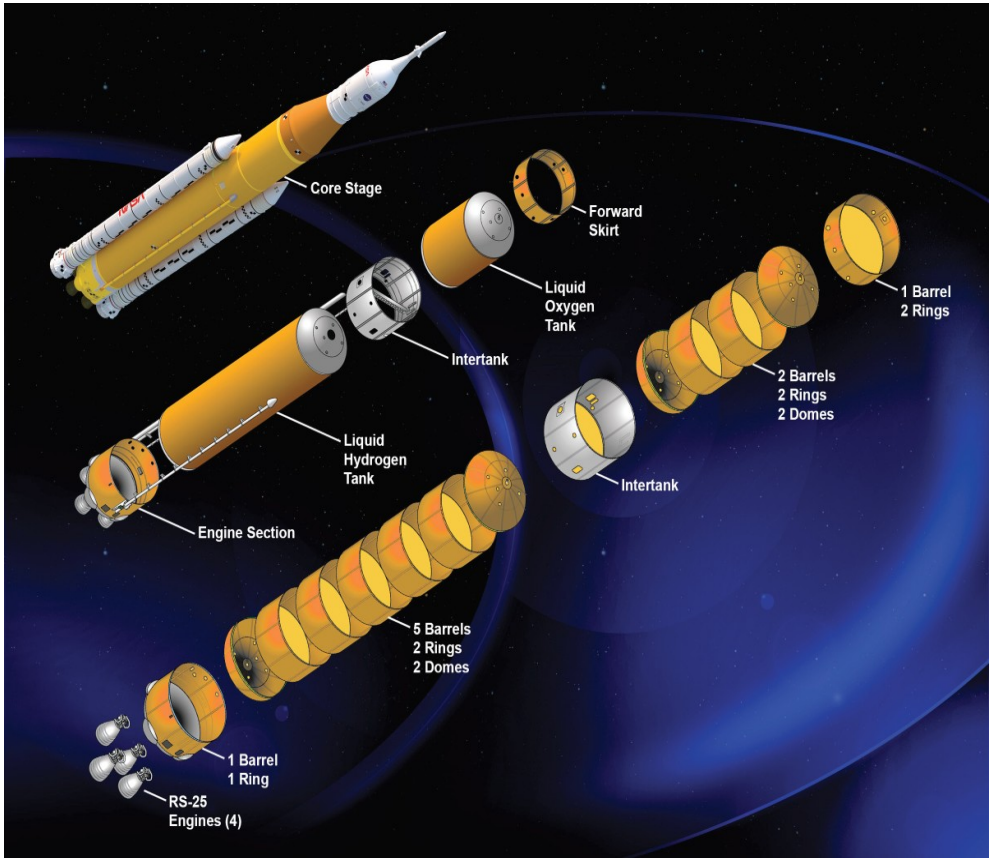
Introduction and Motivation

- The **Core Stage** is the main component of the NASA **Space Launch System**—the launch vehicle for the Artemis Program.
- To certify the **Core Stage** for launch, the **Green Run Test** series was performed at Stennis Space Center in Mississippi, USA.
- **Green Run Test #1** → suspended modal.
- **Goal of Modal Test was to provide correlation data for Core Stage model.**
  - Launch guidance, nav, and control systems



SLS Core Stage

- Consists of 5 components, constructed of AL iso-grid.
- Capable of launching large payloads (59,525-lbs.)
- Covered in spray-on foam for cryogenic fuel insulation.
- Measures 212-ft tall, 28-ft dia., 220,000-lbs (no fuel).
- **Disney World Cinderella Castle only 189-ft tall!**

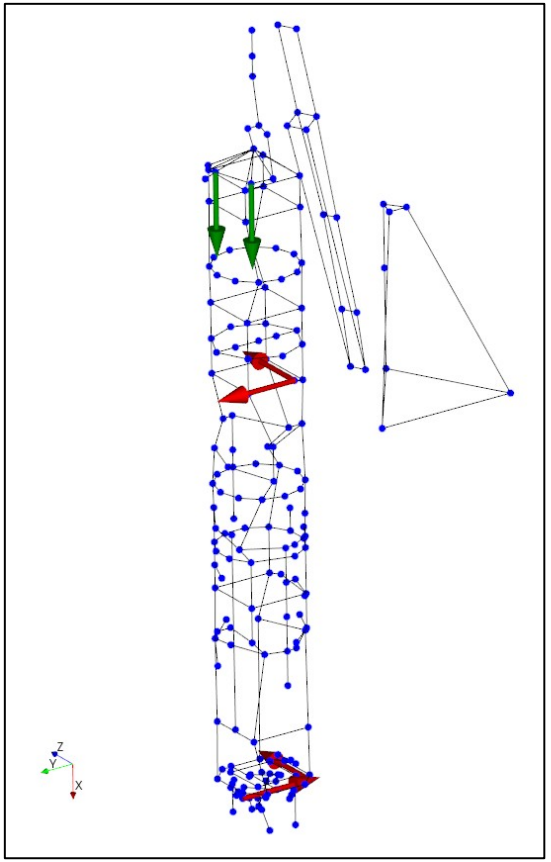


Stennis Space Center B-2 Test Stand

- Hot-fire rocket test facility, 350-ft tall, with water-cooled flame deflector
- Originally built in 1960s for Saturn V, recently modified for **Green Run**.
- Integrated derrick crane with 180-ft boom, lift capacity of 390,000-lbs.
- **Crane = free-boundary condition!**
- Lifting Hardware (below hook)
  - Master Link-precision angular alignment
  - Hydra Set-precision vertical adjustments

Modal Instrumentation

- **Test Goal: 10 target modes from 5 to 15 Hz.**
- Pre-test analysis determined optimal excitation/response locations on Core Stage.
- Response locations also on crane, boom, and rigging to measure the boundary condition (repeated from previous B-2 stand modal test*)
- Response accelerometers (blue)
  - Core Stage/Engines → 100 mV/g, above 0.5 Hz
  - Crane, boom, rigging → 1 V/g, above 0.06 Hz
- Excitation forces:
  - Three 250-lb shakers (red)
  - 12-lb modal sledgehammer (green)



*Stasiunas, et al., IMAC XXXVII

Excitation – Electrodynamic Shakers

- MB Dynamic 250A
  - 250-lbs
  - DC to 4000 Hz
  - 2-in pk-pk
- Load Cells
  - 10 mV/lbf
  - 0.0003 Hz to 36 kHz
- Suspended from stand and mobile jib cranes
- Attached with brackets bolted Core Stage

Excitation – Sledge Hammer

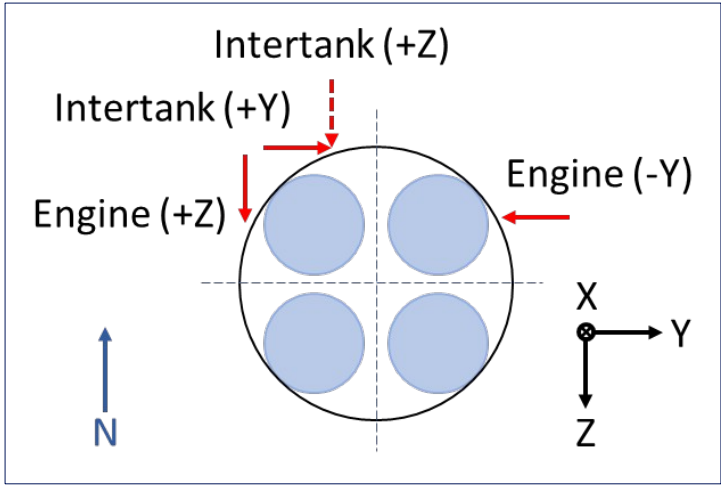
- PCB 086D50
  - 12-lbs
  - 1 mV/lbf
- Spider impacted by engineer on manlift 20-ft up on top of 350-ft B-2 stand.
- **Tester not afraid of heights!!!**

Test Plan

- B&K DAQ (Connect/LAN-XI)
  - Total channels ≈ 561 (force, accel, volts)
  - Signal conditioning → IEPE, HP filter = 0.01 Hz
  - Random shaker excitation signals = 2.5 Hz to 25 Hz.
  - Throughput time data recorded = 512 Hz
- Lift Core Stage 6-inches with Hydra Set.
- Attach shaker stingers, release aft-restraints
- Perform 30 minute multi-shaker random
  - 32-sec frame with 66.6% overlap → Δf = 0.03 Hz
- Perform impact hammer modal tests.
  - 10 impacts, 60 sec. apart → Δf = 0.017 Hz

Test Execution (1/30/2020)

- Core Stage lifted → test start at 12:13 p.m.
- Repair Engine +Z stinger after aft release
- Multi-shaker Engine +Z and Intertank +Y
  - removed Engine Shaker -Y (over-travel)
  - reattached Intertank +Y load cell (stud/F88)
- Hammer Impacts on Spider +X and Engine Shaker -Y (get driving point)
- Multi-shaker Engine Z+ and Intertank +Z
- Parallel modal analysis by GRC and ATA

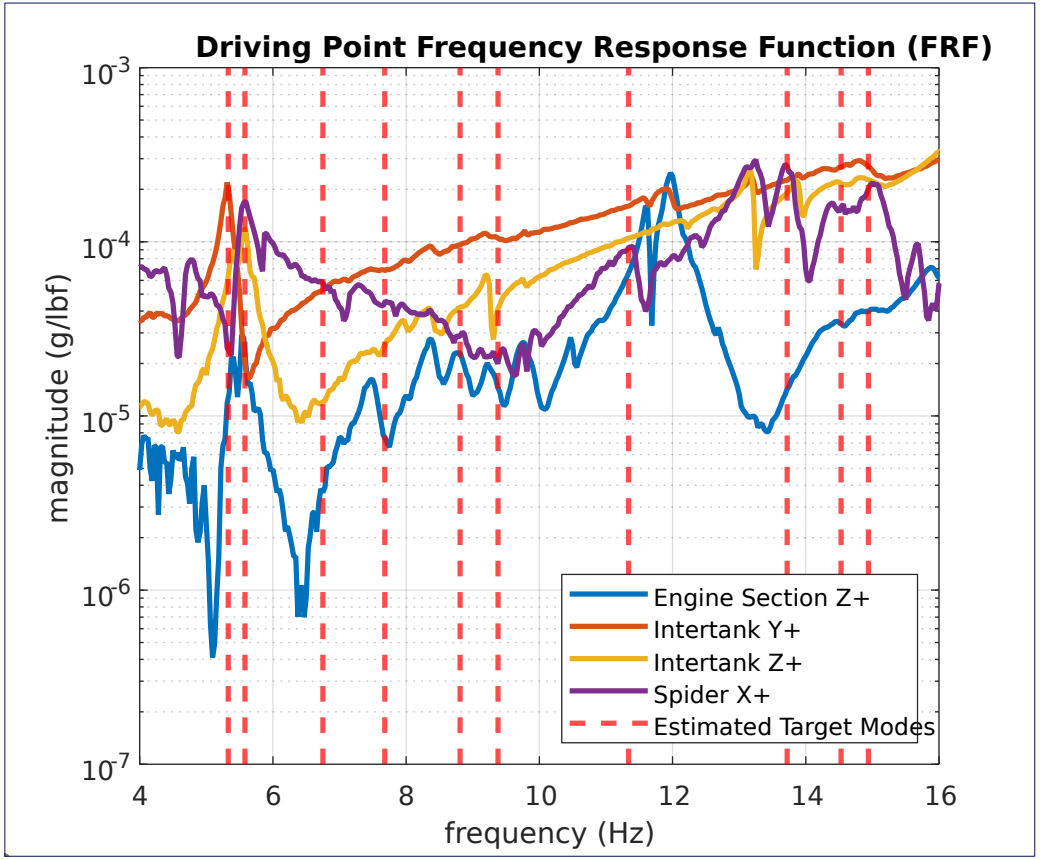


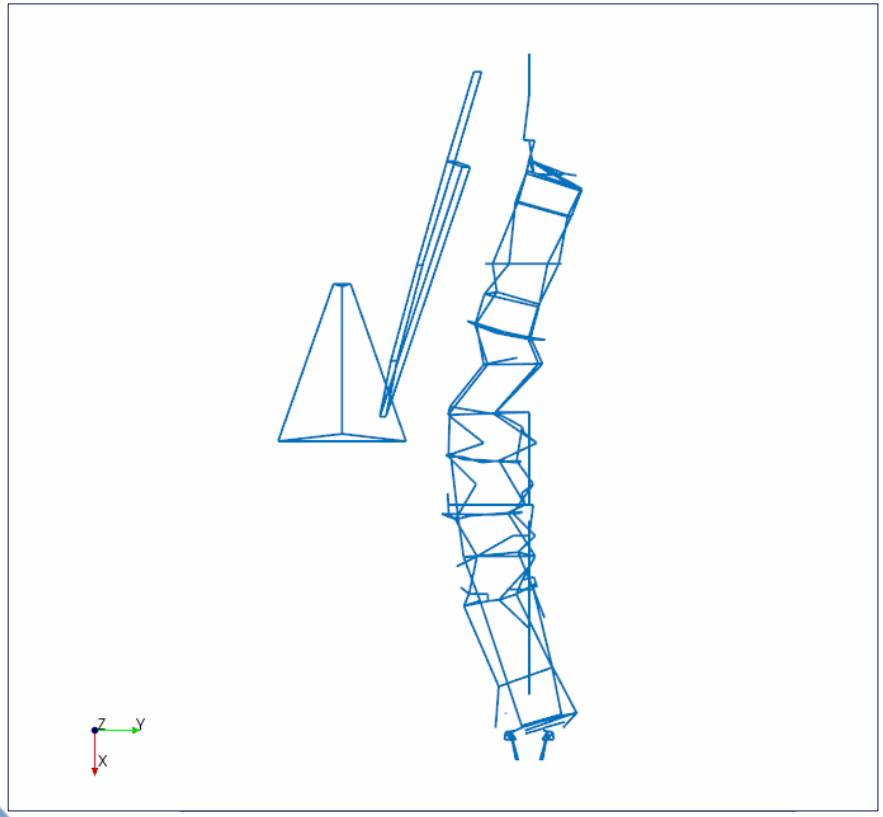
Top-down view of shaker input locations

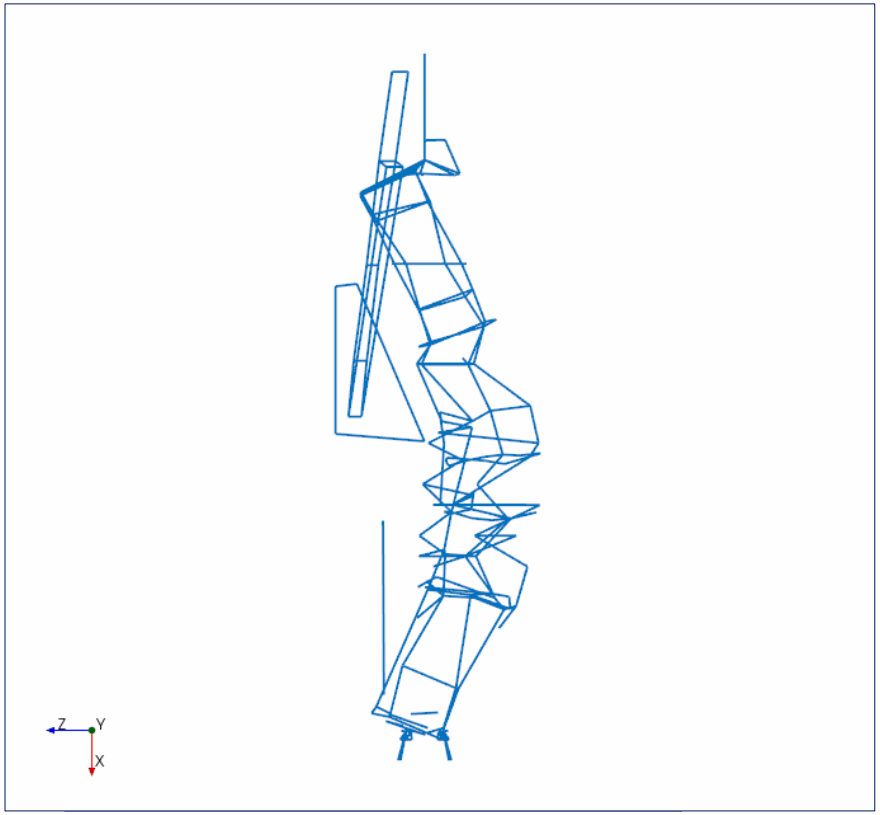
Target modes verified – test complete at 8:30 p.m.!

Test Results – Driving Point FRF

- FRF analyzed with B&K Rational Fraction Poly Z
- The 10 target modes found in data (dashed red lines)
  - 1st bending (near 5 Hz)
  - 2nd bending
  - Torsion and axial
  - Pendulum of RS-25 engines
- Complex Modes Estimated
  - ωn = 5 Hz → 15 Hz
  - ζn = 0.8% → 1.8%







Core Stage First Bending Mode Shapes

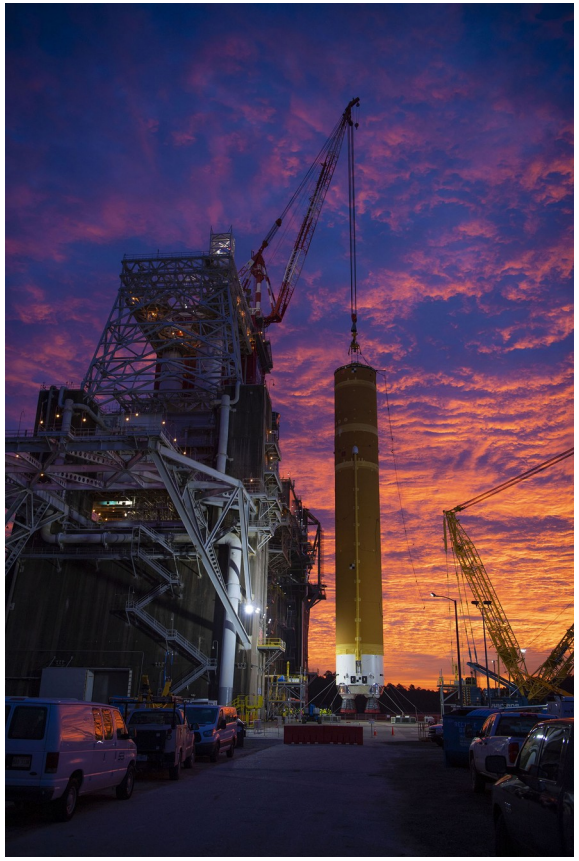
Key Test Factors: Large Item, Limited Time, and Outdoor Location (with bad weather).

- Take photos of each accelerometer insallation to verify location and orientation.
- Run multiple checkout tests prior to test, if time allows to verify instrumentation and hardware.
- **Perform test and modal analysis in parallel**
- Plan contingencies (bad shaker→ hammer)
- Weatherproof instrumentation and cable connectors (Mississippi is very wet).
- Weatherproof test personnel to keep

Challenges

Conclusions

- A successful modal test was performed on the suspended Core Stage as part of Green Run.
- 250-lb electrodynamic shaker and 12-lb modal sledge hammer were used for excitation.
- Ten target modes were estimated from the FRF data (5→15 Hz with 0.8→1.8% damp).
- Multiple challenges were overcome (weather, limited time) to complete ahead of schedule.
- **Ultimately, modal results were used to correlate Core Stage model for certification**



Acknowledgements

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- **Onsite Data Analysis**: Kenneth Pederson and Emma Pierson of NASA GRC and Kevin Napolitano of ATA Engineering.
- **Pre-test Analysis**: Clay Fulcher and Dan Lazor of MSFC.
- **Photos**: NASA.

Backup Slides

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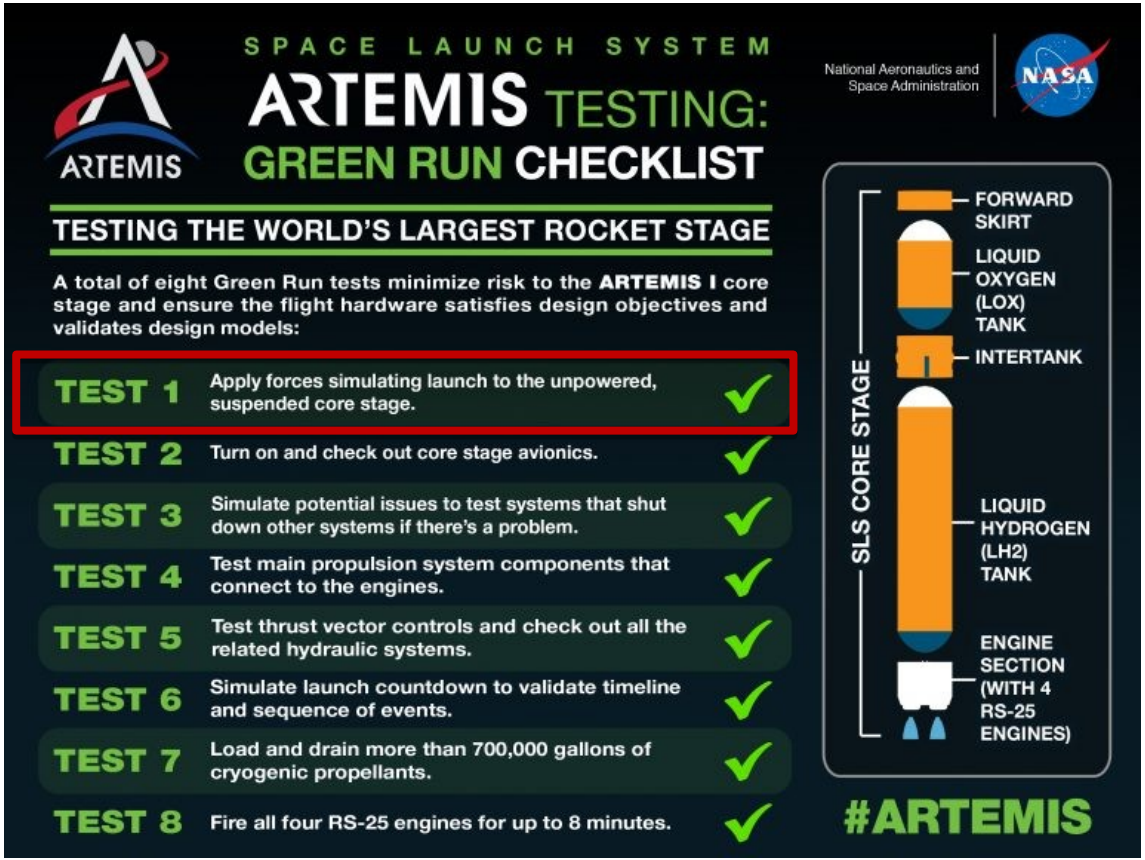
Green Run Test Series

- Designated “**Green**” due to new hardware
- Performed on the SSC **B-2 Test Stand**.
- **Test # 1: experimental modal analysis test**
- Test # 8: hot-fire of the four RS-25 engines, generating up to 1.6 million-lbs. of thrust.



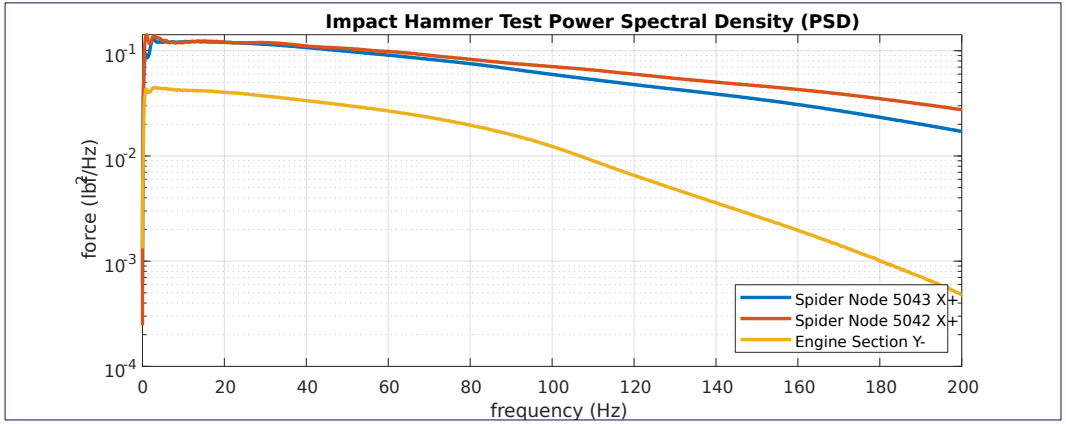
Test Results – Input Force PSD

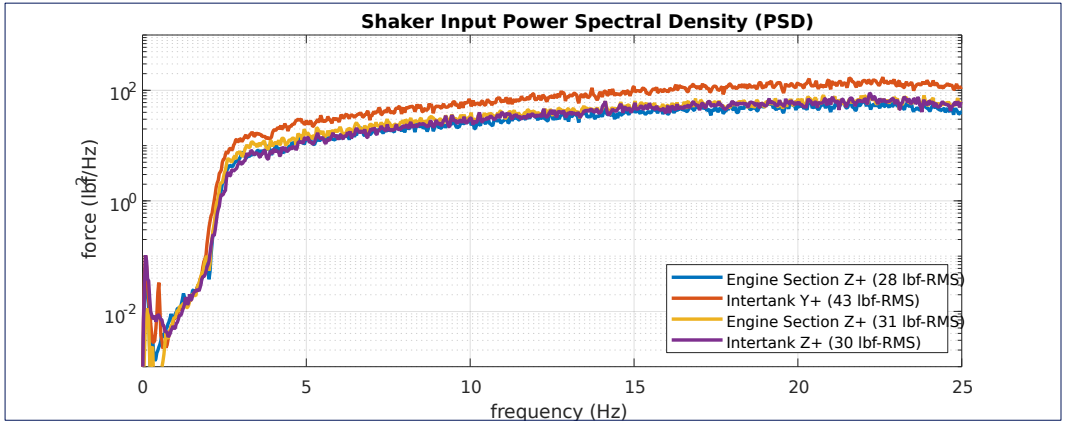
Impact Modal

- 180-lbf peak at Spider.
- 70-lbf peak at Engine -Y
- Sufficient input to 200 Hz
- Hindsight → use softer tip to increase low freq. energy

Random Modal

- Confirmed excitation over freq. range of interest
- Force ranging from
  28 lbf-RMS – 43 lbf-RMS

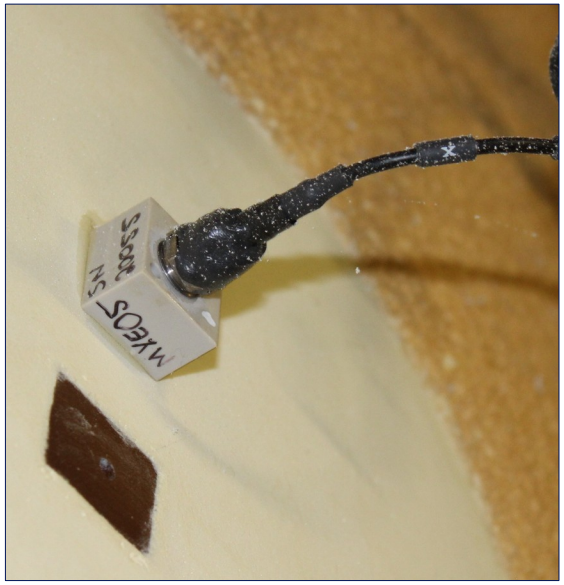




Response – Accelerometers

- All accelerometers hermetically sealed and connectors weatherproofed (electrical tape & sealant) due to harsh MS weather.

PCB 393B04 (crane/rigging)



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